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Melaleuca parvistaminea Byrnes (Myrtaceae) in South Africa: Invasion risk and feasibility of eradication

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ABSTRACT

We document and assess management options for the first reported invasion of *Melaleuca parvistaminea* Byrnes (initially identified as *M. ericifolia*) in the world, in the context of a South African wetland ecosystem. Delimitation surveys indicate that the entire invasion is restricted to three sites between Tulbagh and Wolseley and that populations are only associated with areas currently or previously covered by pine plantations (primarily *Pinus radiata*). To estimate abundance we surveyed 42% of the three identified areas and found ~26,000 plants over 1800 ha (condensed canopy area of 1.15 ha). At least 63% of recorded plants were seedlings or juveniles, mostly <4 yrs old, and most occurred in seasonally inundated (but not waterlogged) habitats. *M. parvistaminea* creates monospecific stands that overtop the native shrubland vegetation (Breede Shale Renosterveld) and is thus considered a potential transformer species. Species distribution modelling also revealed large areas of climatically suitable habitat in the Western Cape, pointing to substantial invasion debt for the species in South Africa. Felling triggers seed release from serotinous capsules, resulting in prolific seedling recruitment after winter rains (up to ~18,000 seedlings/m^2). No evidence of a soil-stored seed bank was found, and when plants are cut at ground level or treated with herbicide after cutting, plants do not resprout. The invasive populations of this water-dispersed species are close to major rivers (the Berg and Breede), but the intervening countryside is largely transformed and is unfavourable for establishment. Much of the area downstream from the invaded area is open vegetation that is unsuitable for major recruitment but easy to survey and detect small plants. Consequently, although the extent of invasion is large (potentially 9185 ha), the invasion can be delimited with some confidence, and eradication is considered achievable since seeds only survive for about a year, seedlings achieve maturity after 4 years, and because the species is an obligate reseeder. Given the threats posed, eradication is desirable and *M. parvistaminea* should be listed as a category-1a invader (requiring compulsory control) under the proposed invasive species regulations under South Africa's National Environmental Management: Biodiversity Act (10/2004). We estimate that search and destroy operations could eradicate the species by 2021 at a cost of ZAR 3 475 000 (US$ 355 400).

1. Introduction

Tree species have been introduced to South Africa for many reasons, including forestry and horticulture (Richardson et al., 2003; Richardson and Rejmánek, 2011). Many species of *Acacia* and *Eucalyptus* from Australia, and *Pinus* species from the Northern Hemisphere were introduced to supply timber, to bind dunes and to provide fire wood. Many of these species have become invasive, their success partly facilitated by the same traits for which they were imported, such as fast growth, and the capacity to fix atmospheric nitrogen (Richardson, 1998; Castro-Díez et al., 2011). The distribution and spatial extent of such invasions are strongly correlated with the extent of planting (Wilson et al., 2011; Procheş et al., 2012) and residence time (Wilson et al., 2007), suggesting that the extent of invasions is more strongly influenced by the extent and timing of human usage than by particular traits of the species (McGregor et al., 2012). If this is the case, many species introduced to only a few sites and which still have relatively small invasive ranges, pose a substantial threat to ecosystems if they are allowed to spread and/or to be disseminated further by humans (see also Donaldson et al., 2014a,b). The concept of "invasion debt" (Essl et al., 2011) posits that even if introductions cease new invasions will continue to emerge and already-invasive species will continue to spread and cause potentially greater impacts, since large numbers of alien species are already present, many of them in a lag phase. Cognizance of these factors is particularly important where introduced species have been

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historically planted in low numbers at a few sites, but then not subsequently managed and left to invade unchecked (Wilson et al., 2013). Such species are often suitable targets for eradication (Zenni et al., 2009; Kaplan et al., 2012, 2014). The Invasive Species Programme of the South African National Biodiversity Institute is responsible for detecting such invasions and for evaluating whether eradication (i.e. total removal of all plants and propagules) is feasible (Wilson et al., 2013).

Thirty-four species in the family Myrtaceae are known to be invasive globally (Rejmánek and Richardson, 2013). Of these, some fleshy-fruited species (notably *Psidium*, *Eugenia* and *Syzygium* species) are used for food, *Eucalyptus* species are widely planted for forestry, and 24 species (including *Melaleuca* taxa) are widely used as ornamentals. However, only one species in the genus *Melaleuca* has been recorded as causing major impacts as an invader. *Melaleuca quinquenervia* is a notorious invader in the Florida Everglades, USA (Serbesoff-King, 2003). Although 27 *Melaleuca* species are listed in the Global Compendium of Weeds (Randall, 2007), the invasive status (sensu Richardson et al., 2000) of most is questionable because they are only weedy close to sites where they are considered native. *M. quinquenervia* has been recently detected in South Africa (van Wyk et al., 2012), prompting a re-evaluation of the state of all introduced *Melaleuca* species in South Africa.

It has been proposed that *Callistemon*, a sister genus, should be included in *Melaleuca* because characters upon which the separation of the two were previously based are continuous (Craven, 2006). Although recent analyses using molecular and morphological data support the inclusion of *Callistemon* within *Melaleuca* (Edwards et al., 2010), some Australian state herbaria still recognise *Callistemon* as a separate taxon (Udovicic and Spencer, 2012). Many species of *Melaleuca* and *Callistemon* have been moved widely around the world only fairly recently. Many are traded in horticulture (Richardson and Rejmánek, 2011) and some also have major pharmaceutical value (e.g. tea tree oil from *M. alternifolia*; Tripathi et al., 2011). In South Africa, 16 *Callistemon* and 27 *Melaleuca* species are known to be cultivated (Glen, 2002). Although no *Callistemon* or *Melaleuca* taxa are listed in Poynton's (2009) book "Tree planting in Southern Africa: vol. 3 Other Genera", three *Callistemon* and eight *Melaleuca* species are listed in the Southern African Plant Invaders Atlas, indicating a degree of naturalisation or invasion (Henderson, 1998; van Wyk et al., 2012; Wilson et al., 2013). One *Callistemon* species (*Callistemon rigidus*) was listed as an "emerging invader" in an analysis that prioritized alien plant species and areas for management action in South Africa (Nel et al., 2004).

M. quinquenervia was found naturalised at two sites in the Western Cape (Wilson et al., 2013). At one of these sites a far larger invasion of another species, *Melaleuca parvistaminea*, was found. The last-mentioned species is not known to be invasive anywhere in the world (Rejmánek and Richardson, 2013). Initial work on *Melaleuca* in South Africa by the Invasive Species Programme focussed on *M. quinquenervia* because of its prominence as an invasive plant in Florida and therefore its perceived high-risk status in South Africa. *M. parvistaminea* is however currently much more widespread and is currently having a much greater impact on the local environment than *M. quinquenervia* (van Wyk et al., 2012).

This study aims to: a) determine the risk posed by *M. parvistaminea* as an invasive species in South Africa (this being the first record of invasiveness anywhere in the world); b) assess the current national-scale distribution and population dynamics at the known sites of invasion; and c) develop recommendations for management, and specifically to determine whether eradication is feasible.

2. Materials and methods

2.1. Study species

M. parvistaminea is a small tree or shrub up to 4 m tall, native to New South Wales and Victoria in Australia (Albrecht, 1987). It has whitish, bottle-brush like flowers (Fig. 1) with conspicuous stamens typical of many species in the genus and to some extent, the family Myrtaceae. Flowering occurs only from September to November. The species was found to be naturalised in the Western Cape province of South Africa during routine conservation management inspections in the spring of 2007. It was identified as a problematic species, as it had already formed monospecific stands (Fig. 1). The species was initially identified as *M. ericifolia*, but was later found to be *M. parvistaminea*, a close relative (see Supplementary Material 1 for discussion on species identification).

Although *M. parvistaminea* is reported as an environmental weed in Australia in the Global Compendium of Weeds (Randall, 2007), this record from SE Australia is likely within its native range (Supplementary Material 2), and so does not qualify as invasive under the biogeographic definition of Richardson et al. (2000). The occurrence of *M. parvistaminea* in South Africa is therefore the first record of invasiveness (sensu Richardson et al., 2000) anywhere in the world.

2.2. Study site

The three known localities of *M. parvistaminea* in South Africa are in a narrow area between the towns of Tulbagh and Wolseley in the Western Cape (Fig. 2b; Table 1). The area is situated between the slopes of the Waterval Mountains and the cultivated lowlands of the Upper Breede River valley. Before 2000, most of this area was managed solely by forestry companies but since then parts of the area are in transition from pine plantation to nature conservation, following the recent exit strategy for commercial forestry in the region (Louw, 2006). The remaining plantation (and some of the areas no longer under forestry) is subdivided into management blocks (~300 m × 300 m) separated by gravel roads, which made the management of the survey easier (Fig. 2D). A nursery is situated near the Kluitjieskraal forestry station, and several *Melaleuca* species have naturalised in the area, though *M. parvistaminea* is by far the most widespread of these (van Wyk et al., 2012).

Since the first report of the invasion in 2009 at the Waterval site, the extent of *M. parvistaminea* has been estimated by gaining insights from land managers and active walked surveys following the approach taken by Kaplan et al. (2014).

In the Kluitjieskraal plantation and wetland (Fig. 2B, D) an ex-forester in the area knew where many of the sites of invasion were (indicated on Fig. 2B) although he was previously unaware that the species was a non-native melaleuca. While these records served as a very valuable starting point for surveys (cf. Kaplan et al., 2012, 2014), all blocks were regarded as potentially invaded.

The Kluitjieskraal Wetland (Fig. 2B) is being rehabilitated by the Working on Wetlands programme and was also previously covered by *Pinus radiata*. The Kluitjieskraal wetland is characterised by seasonally and permanently wet areas. As part of wetland rehabilitation efforts, clearing of major invaders took place prior to this study, but no evidence of previous *M. parvistaminea* clearing was found. A clearing contract (220 ha), which aimed to clear *M. parvistaminea* plants and to collect data, was initiated by SANBI's Invasive Species Programme at this site in April 2012 (Fig. 2E).

The Waterval site (Fig. 2C) is designated as a "forestry exit" zone, i.e. it has been identified as being unsuitable for sustainable commercial forestry as part of a national forestry strategy. Pine plantations in the area (as well as invasive species — notably Australian acacias and eucalypts) are being cleared, the aim being to restore the natural fynbos vegetation. The area has been managed by the provincial conservation authority (CapeNature) since 2000 (Table 1) (Nagan, 2008). Despite the clearing of major invaders in the area, *M. parvistaminea* was allowed to persist, almost certainly because it was mistaken for a native species. Some data collection and initial clearing took place at this site before it burnt in January 2012.

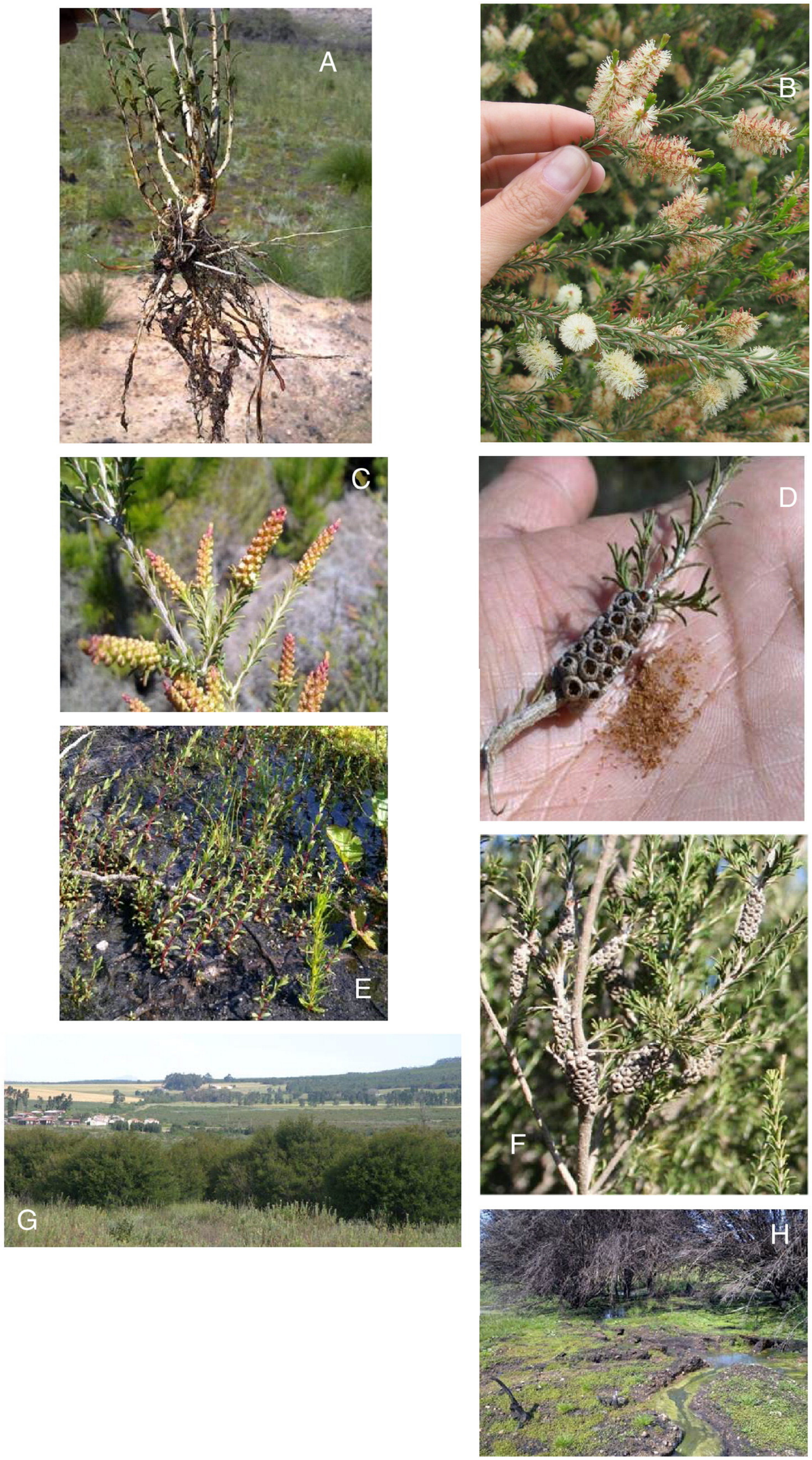

Fig. 1. *Melaleuca parvistaminea* in the Tulbagh-Wolseley area, Western Cape, South Africa, A) multi-stemmed seedling, B) whitish bottlebrush-like flowers, C) pinkish petals on flower buds, D) seed release one week after cutting a twig, E) post-fire recruitment in wet areas in August 2012, F) serotinous seed capsules on branches, G) virtually monospecific stands of *M. parvistaminea* overtopping native vegetation, and H) profuse seedling recruitment near burnt adult trees.

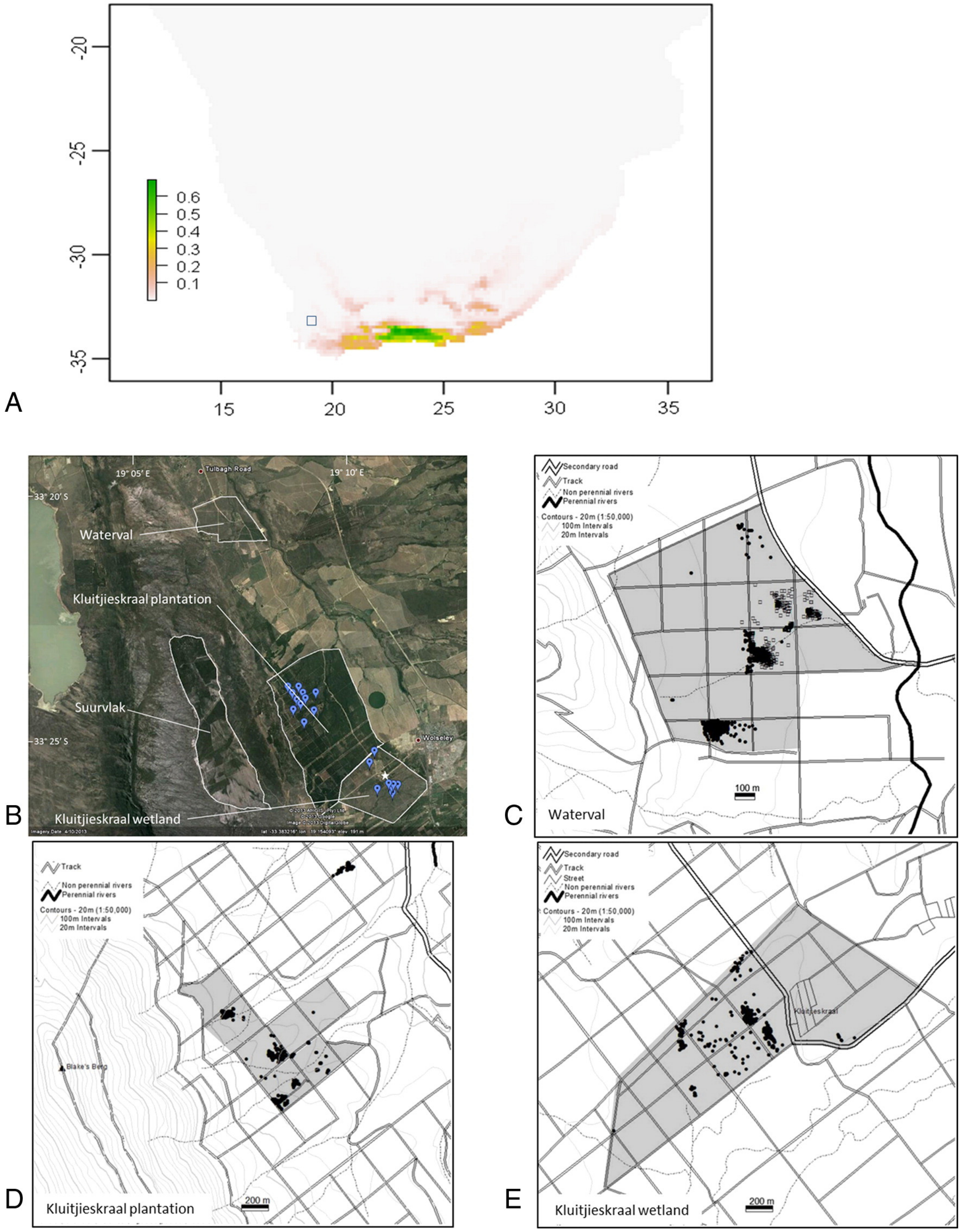

Fig. 2. *Melaleuca parvistaminea* in the Western Cape, South Africa: A) bioclimatically suitable areas (green shading indicates most suitable areas) predicted for *Melaleuca parvistaminea* in South Africa (the open square indicates the study area), AUC = 0.998; B) survey sites in the Tulbagh–Wolseley area (Table 1), with *Melaleuca parvistaminea* presence localities (blue icons) identified by a local forester. The Kluitjieskraal forestry station and nursery are indicated by the star; C) plants found at the Waterval site open squares indicate data collected before the January 2012 fire; D) plants found in the Kluitjieskraal plantation; and E) plants found in the Kluitjieskraal wetland. Solid circles represent burnt plants at Waterval (C), but represent live plant data at Kluitjieskraal plantation and Kluitjieskraal wetland (D, E) collected during this study. At the three sites (C–E), grey shading indicates surveyed area and at Kluitjieskraal wetland shading also indicates the clearing contract area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3. Delimiting the extent of M. parvistaminea in South Africa: national, regional, and local surveys

When attempting eradication, delimiting the extent of the invasion is a crucial factor for success (Panetta and Lawes, 2005). To determine whether any other localities of *M. parvistaminea* existed in South Africa, tree planting records, the iSpot website (http://www.ispot.org.za/) and herbarium specimens were examined, and numerous botanists and foresters were consulted. Pamphlets (Supplementary Material 3) with contact information, pictures and a description of *M. parvistaminea* were distributed to land managers within the region known to be the focus of planting activities. As part of the regional-scale delimitation strategy,

Table 1
Summary of characteristics and management of *Melaleuca parvistaminea* at three sites in the Tulbagh–Wolseley area in the Western Cape, South Africa. The natural vegetation type at all sites is Breede Shale Renosterveld (Mucina and Rutherford, 2006). The species was introduced for used as an ornamental plant or for windbreaks before 1990 at all three sites. Fig. 2b shows a map of the sites within the landscape.

	Kluitjieskraal plantation	Kluitjieskraal wetland	Waterval
Location	S 33.4113° E 19.1574°	S 33.4297° E 19.1801°	S 33.3410° E 19.1158°
Size of area	1392 ha	538 ha	294 ha
Previous land use (before 2000)	Pine plantation	Pine plantation	Pine and eucalypt plantation
Current land use	Mainly pine plantation	Conservation (wetland rehabilitation)	Conservation
Local authority	MTO Forestry	MTO Forestry	CapeNature
Record present in SAPIA database before project initiation	No	Yes	No

CapeNature and MTO forestry staff assisted as "spotters" for the species throughout the area. Besides the study sites, suitable sites for *M. parvistaminea* were determined by including likely areas of dispersal and establishment, while excluding unsuitable areas based on unlikely habitat type and cultivated or urban areas.

Each site identified as invaded by the local forester in the Kluitjieskraal plantation was systematically surveyed by walking parallel transects (Fig. 2D). As evidence of surveyed area, a track of the walked transects and waypoints of plants were taken with a handheld GPS (Garmin GPSmap 60CSx) (e.g. Zenni et al., 2009; Kaplan et al., 2012). No tracks were taken at the Waterval and Kluitjieskraal wetland sites.

To estimate the population dynamics and size of the invasion, all plants were counted and ~5000 were measured. Plant height, canopy width, stem diameter and evidence of reproduction (presence of seed capsules and/or flower buds) were recorded. Due to time constraints, midway through data collection, it was decided to prioritise survey effort. Thereafter, plants were counted and only the geographic position was recorded. To assess age and size at reproduction, two 50 × 50 m plots (1 dry site, 1 wet site) were selected in a densely invaded area (>100 individuals per plot) that contained both seedlings and adults to ensure size and age range over a reasonable sample size. To do this, stumps were cut as close to the ground as possible and the age rings were counted in addition to the measurements described above. Since not all plants were aged, we attempted to find a relationship between physical measurements and plant age. The primary aim was to determine the size at which *M. parvistaminea* plants reach reproductive maturity and to inform monitoring protocols for the species.

At the Waterval site, distribution and plant allometric data were collected during 2009 and 2010. We surveyed the remaining population after the fire in January 2012 by counting and measuring burnt skeletons. Burnt individuals could only be identified where capsules were present (where these were absent *M. parvistaminea* skeletons could not be distinguished from several native shrub species); abundance is therefore likely to be underestimated. Only plant height, canopy width and stem diameter were measured at the Kluitjieskraal wetland by clearing contractors.

The extent of occurrence at each site was determined by calculating the area of a convex hull drawn around the most outlying points within each population. Condensed canopy, i.e. fine-scale area of occupancy, was calculated by adding a buffer equal to the canopy width per plant to each point, then by summing the area contained with each buffered point (Wilson et al., 2014). These spatial analyses and maps were produced in ArcGIS 10 (ESRI, 2011); statistical analyses were conducted in R (R. Development Core Team, 2012).

2.4. Risk assessment and bioclimatic modelling

To collate information, determine invasive potential and identify areas requiring more research, the Australian Weed Risk assessment scheme (Pheloung et al., 1999) was used. This scheme has been applied in a variety of geographies and is reported to be consistently accurate (Gordon et al., 2008, 2010; Hulme, 2012). It also provides a standard method for collating information on potential impacts. The qualitative level of threat was also evaluated by determining by a) whether the species could over-top native vegetation; and b) whether it had (or could have) the properties of a transformer species (Wilson et al., 2014).

To determine which areas are climatically suitable and therefore at risk of invasion by *M. parvistaminea* in South Africa, we modelled the climate niche using the algorithm MaxEnt 3.3.2 (Phillips et al., 2006). Presence data were downloaded from the Atlas for Living Australia (http://www.ala.org.au) and the Global Biodiversity Information Facility (http://data.gbif.org). Points outside the reported native range in Australia, duplicate records, points where the location was not recorded with an accuracy of at least 1km (including points where the accuracy was not recorded, but the locality was specified only to the nearest minute or hundredth decimal degree) and points in the ocean were removed manually. We aimed to verify climatic suitability (and not potential distribution in South Africa), therefore points in South Africa were also excluded. The bioclimatic variables were obtained from the WORLDCLIM dataset (www.worldclim.org) at 10 min resolution. The least inter-correlated variables included in the model were: isothermality, mean temperature of the driest quarter, mean temperature of the warmest quarter, precipitation seasonality and precipitation during the wettest quarter. For model verification, we report the area under the curve (AUC) statistic.

2.5. Post-clearing efficacy and post-fire recruitment

The reseeding habit of many serotinous species is characterised by adult mortality after fire which leads to seed-release from woody storage structures. This is then followed by profuse seedling recruitment in the low competition post-fire environment (Lamont et al., 1991). Post-fire recruitment at the Waterval site (burned in January 2012) was evaluated using a transect through a population of burnt adults. Adult survival after fire was also noted. Seedlings were counted in 1 × 1 m quadrats (centre positioned on the line) at 1-m intervals along the length of the transect, using a combination of actual counts and estimation based on coverage.

Plants were cleared immediately after data collection at the Waterval site in 2009 and 2010. The only other targeted clearing to date was in a subsection of the Kluitjieskraal wetland during April and May 2012 (the shaded area in Fig. 2E). Field observations at the Waterval site during 2010 informed clearing recommendations for the Kluitjieskraal wetland contract, thus providing an opportunity to evaluate post-clearing regeneration and the success of clearing operations. At the contract site, workers were asked to stack dead material (with seed capsules attached) in large piles (~25 m^2) in dry areas to minimise the area over which recruitment would take place (seeds require seasonally waterlogged soils for germination) and also to minimise the search area during follow ups. After winter (and seasonal rains), we specifically checked for adult plants that had been missed during clearing, seedling recruitment beneath and around stacked dead material, seedling recruitment around cut stumps, resprouting after cutting and herbicide application, and for dead material not stacked on a pile or in wet areas.

Indiscriminate clearing of *M. parvistaminea* has however taken place at the Kluitjieskraal plantation. Brush-cutting of trees and shrubs around pine trees was part of routine plantation maintenance, and herbicide was not applied to cut stumps (as per standard protocols). This allowed us to observe the effects of brush-cutting on recruitment and clearing efficacy.

2.6. Estimate of cost for eradication

To determine the cost of eradication we extrapolated the costs of surveying and clearing to the total area. Using this information we estimated the total cost to achieve eradication (removal of all plants in the study area). Cost until eradication also included the amounts needed for surveying all likely areas (including delimitation surveys) before clearing. Follow-up costs were also projected using information on reproductive age and seed storage to determine the timing and frequency of follow ups. Time was measured in person days (number of days × number of people per day).

3. Results

3.1. National and regional survey

The population in the Tulbagh–Wolseley area is the only one we could confirm in the country. No additional records for *M. parvistaminea* were discovered via pamphlet distribution, surveillance by “spotters”, iSpot records or herbarium specimens in 2012. This species is not listed in any tree planting records nor is it being cultivated as an ornamental plant, suggesting that no populations exist outside of the Tulbagh–Wolseley area. Our observations with delimitation surveys in and around the three sites indicated that *M. parvistaminea* is only in the plantation areas in the vicinity of Kluitjieskraal.

An additional locality was reported by a contractor working at the Suurvlak plantation (indicated in Fig. 2B and in Fig. 4 as “unconfirmed report”). To verify this, we drove along gravel tracks through the plantation in suitable areas but failed to find any plants. Detectability was high in most areas because this area also burnt in January 2012. It is therefore likely that large, highly visible plants were destroyed in the fire or that this record is erroneous.

3.2. Local delimitation and population dynamics

372 ha (42% of all areas earmarked for surveying) has been surveyed to date, including all areas identified by the forester at Kluitjieskraal plantation (Fig. 2B). A total of 26,302 plants (condensed canopy area of 1.15 ha) were recorded at the Waterval, Kluitjieskraal plantation and Kluitjieskraal wetland sites (Fig. 2C, D, E). For data where presence/absence of reproductive structures were recorded, 37% of plants were mature; the remainder were seedlings or juvenile plants. At Waterval, a total of 6629 plants were recorded. During 2009 and 2010, 2074 plants were recorded and measured. In 2012, the remainder of the population was surveyed after the January 2012 fire. We counted 3805 burned trees which is an underestimate of the actual numbers before the fire. Burnt trees were difficult to identify when seed capsules were absent, while no evidence remained of juvenile plants and seedlings after the fire. Regular CapeNature patrols and our observations at the Waterval site suggest that it is unlikely that any unburned adult plants are present.

Abundance varied hugely between management blocks (range = 0–14,863 plants), which made survey planning unpredictable and difficult, and also to determine the source of the invasive populations. Survey and clearing contracts will be issued by SANBI's ISP to address the remaining area. Approximately 20,300 plants were recorded at Kluitjieskraal plantation over 58 ha.

The clearing contract at Kluitjieskraal wetland (Fig. 2E) surveyed and cleared 220 ha during April and May 2012 (292 person days). 1822 plants were found. Therefore 318 ha must still be surveyed, potentially containing 2634 plants (assuming that densities are the same).

The strongest correlation was found between age and log maximum height (Pearson's correlation co-efficient between age and maximum height ($r = 0.64$), average height ($r = 0.33$), stem diameter ($r = 0.52$) and canopy width ($r = 0.33$). Using a linear regression model, maximum height was used to predict the age of individual plants (and so of the various invasive populations).

Plants bear seeds at age 3–5 years, and 40% of plants carry seeds at four years (Fig. 3). Small plants (stem diameters < 1 cm) were difficult to age, and therefore ages of mature plants that were three years or less were possibly underestimated.

3.3. Bioclimatic suitability and invasive risk assessment

The areas predicted to be climatically suitable fitted well with the *M. parvistaminea* native distribution in Australia (AUC = 0.998, Supplementary Material 2). Although the southern parts of Western Cape Province (Fig. 2A) are climatically very similar to the natural range of *M. parvistaminea*, the Tulbagh–Wolseley area where the only known invasive populations of the species occur at present is not climatically similar. Precipitation seasonality (33%) was the best contributor to the model, followed by isothermality (mean diurnal range/temperature annual range) contributing 31.2%.

In terms of an invasive risk assessment, 41 of the 47 questions relevant to *M. parvistaminea* were answered, leading to a score of 9 which would have resulted in the species being rejected in a pre-border evaluation (Supplementary material 4). According to the assessment, both agriculture and environmental sectors are at risk from invasion by this species. This species can clearly form dense monocultures (Fig. 1G) and overtop native vegetation (Breede Shale Renosterveld); its impacts are therefore likely to be similar to other invasive shrubs in the region that form impenetrable stands (reviewed by Richardson and van Wilgen, 2004). Wetter areas are preferred and dense stands form in seasonally waterlogged wetlands, posing a considerable threat if allowed to establish in large numbers after fire (Fig. 1E, H).

3.4. Post-clearing efficacy and post-fire recruitment

A follow-up survey indicated that cut material was not always stacked in the allocated dry areas. Seedling recruitment where cut adult plants had released seeds was observed in these areas. Fifty-two plants (mean height 172.9 cm, 158.4–187.4, 95% CI) were missed (3% of plants in the

Fig. 3. Age at onset of reproduction for *Melaleuca parvistaminea*, indicating that 40% of plants were reproducing by the age of five. The curved line is from a fitted generalized linear model with binomial errors and log (age) as explanatory variable (n = 617).

contract area); highlighting the role that monitoring and evaluation will have to play if eradication is to be achieved. Seedling recruitment at the allocated dead material stacks was restricted to shaded areas beneath the dead material. Searching should therefore focus on shaded areas in the vegetation and seedling establishment could be reduced by treating these shaded areas with herbicide. We observed no coppicing after cut stumps were treated with herbicide during April and May 2012. At the Waterval site, profuse germination (up to 18,000 seedlings/m^2, mean 4700 seedlings/m^2, 2600–6700 95% CI, n = 29) was recorded within the canopy area of the burned adult plants, although low numbers were recorded up to 50 m away from adults. We observed that adult skeletons shade seedlings thereby improving likelihood of survival.

No herbicide was applied to 419 plants that had been cut at 23 ($\pm$12) cm high (as a result of indiscriminate brush cutting as part of routine management block maintenance). These plants coppiced. We also observed several large plants (stem diameter greater than 5 cm) that had been cut less than 10 cm from the ground. There was no indication that herbicide had been applied (a coloured paint is routinely administered with herbicides), but these plants showed no signs of regrowth. This suggests that clearing efficacy is dependent on the height of the cut as well as herbicide application to cut stumps. Cut material was not removed from the area and was often found adjacent to resprouting plants. Profuse recruitment was sometimes seen near cut plants, i.e. large numbers of young plants of a similar age were observed.

3.5. Cost for eradication and management strategy

Our surveys indicated that *M. parvistaminea* is confined to the area between the Waterval Mountains and unsuitable cultivated/urban land of the Breede River Valley (Fig. 4). Fig. 4 indicates suitable areas (characterised by Breede Shale Renosterveld associated with forestry management) where *M. parvistaminea* could occur; this area will be the focus of future "search and destroy" contracts. To verify that the species had not spread along likely streams, we surveyed ~5 km downstream of the Kluitjieskraal wetland and Waterval and found no plants.

Remaining areas at the three sites need to be surveyed. Based on the costs of surveying (without clearing), we estimate that a further ZAR 300,000 is required to survey (without clearing) the remaining 1852 ha in 2014. Assuming that the remaining area at the Waterval, Kluitjieskraal plantation and wetland sites have invasive populations of similar density and that no new populations are found during the delimitation surveys, ZAR 427000 is needed to clear all plants. Initial clearing should be completed by the end of 2014. A main aim of management is to prevent seed production, and eradication can only be declared once all current seedlings are detected and controlled before they set seed. Since >90% of the plants will flower at 7 years (Fig. 3), we estimate that eradication could be declared if no mature seed-capsules are observed on plants for seven years and there are at least two full surveys conducted that did not find any plants. Again assuming that all areas are invaded, follow-up surveys with clearing of seedlings and juvenile plants in the entire area will cost ZAR 496,000 each. Plants smaller than 0.8 m in height (and younger than 4 years) are unlikely to flower and due to similarity of native ericoid shrub species to these juveniles, low levels of detectability are expected for these plants. We therefore recommend that search and destroy operations should take place annually to prevent seed set in any missed plants. Thus we estimate that annual search and destroy operations for the next 7 years will cost ZAR 3 475,000 and eradication could be declared in 2021 at the earliest. Results regarding the *M. parvistaminea* invasion have been consolidated in Supplementary Material 5.

4. Discussion

While eradication of invasive plants occurring over areas greater than 1000 ha has been shown to be difficult to achieve in the past (Rejmánek and Pitcairn, 2002), several features of this invasion both

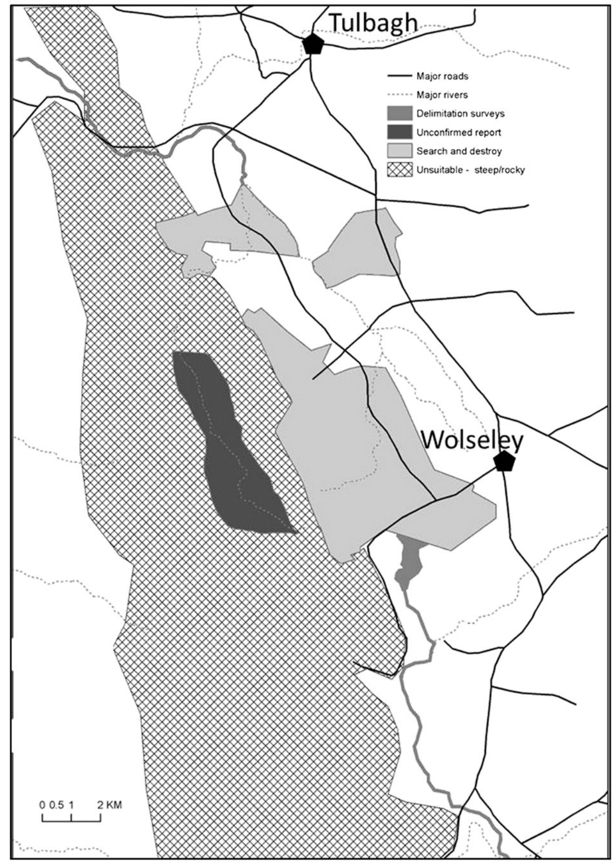

Fig. 4. Different management strategies that should be implemented in areas across the landscape. These strategies are: search and destroy in suitable and likely habitat, delimitation surveys that were undertaken along likely dispersal routes, i.e. streams, and during flowering time scanning an area where a report remains unconfirmed. Areas deemed unsuitable for *M. parvistaminea* on the basis of habitat are also indicated, and will therefore not be surveyed. Cultivated and urban areas are also unsuitable; these are indicated as white areas on the map.

in terms of the biology of the plant and the management context suggest that eradication of *M. parvistaminea* (invasion ~ 1800 ha) could be achieved in South Africa. *M. parvistaminea* is also a desirable target for eradication as monospecific stands are likely to over-top native vegetation, the species has the traits of a transformer species (excessive user of resources and a fire promotor, sensu Richardson et al. (2000)) and so the invasion will likely have a large impact if given time and allowed to spread to suitable habitats.

4.1. Origin of the invasion

At the Waterval site evidence of large decaying adult trees were observed. This observation and age-ring data taken during the study suggest that the species was introduced before 1990 (~10 years prior to when the oldest plants established). Although Richardson and Rejmánek (2011) recorded this species (listed as *M. ericifolia*) as an ornamental plant, we could find no evidence of this species being introduced or sold for this purpose in South Africa (Poynton, 2009) and neither were any planted trees recorded. We suspect that the plants were introduced to the Kluitjieskraal nursery (van Wyk et al., 2012), and that seeds dispersed from there in soil used for planting of pine seedlings.

4.2. Local delimitation and population dynamics

Failed eradication attempts are commonly characterised by lack of population delimitation (Panetta and Lawes, 2005; Panetta et al., 2011). We recommend therefore that the unconfirmed report at Suurvlak plantation be resurveyed by systematic searching when plants are likely to be more detectable and assuming all adult plants were destroyed in the fire of January 2012, this should be done in 2014 to coincide with first flowering. The absence of established plants along tributaries of the Berg and Breede rivers supports our case for eradication of the species.

From initial surveys and the lack of other records, we conclude that naturalised populations of *M. parvistaminea* are currently restricted to the Tulbagh–Wolseley area. In this one area there are now several clear foci of invasions across a spectrum of land-use types with a distribution large enough that it should be classified as fully invasive, i.e. category E under the Blackburn et al. (2011) scheme. Spread is only through seeds which require water for germination (Robinson, 2007) and is encouraged by fire and clearing which triggers seed release. Seeds remain viable for one year (Robinson, 2007), suggesting that a long-lived soil seed bank is absent. This favours a much shorter time for eradication than for some of the Australian acacias (Wilson et al., 2011).

4.3. Management recommendations

Implementing an eradication plan for the first known invasion by this species anywhere in the world would have substantial significance from a management perspective, but much of the work still needs to be done.

Areas which are particularly at risk in South Africa are those with similar land use and habitat requirements. Places where Breede Shale renosterveld is associated with plantation or forestry exit areas are likely candidates for further surveying. The bioclimatic model however indicates that the Tulbagh–Wolseley area is not ideal for *M. parvistaminea*. Of concern is the fact that the southern Cape (Fig. 2A) is highly suitable for this species. These areas will form the basis for continued regional and national scale surveys for *M. parvistaminea*.

No prior intentional management of the species has taken place at any of the sites that were surveyed. Clearing of *M. parvistaminea* (among several other native and alien species) as the unintended part of routine maintenance of pine-planted blocks has been largely ineffective (due to a lack of herbicide application and cutting too high above the ground) and likely triggered seed release contributing to spread. Plants at the Kluitjieskraal wetland were probably missed because they were not flowering at the time of clearing (April–May 2012). GPS tracks were not taken during the clearing operations and the effectiveness of the management could therefore not be verified. Systematic survey methods need to be followed if eradication is to be achieved and documented. To prevent spread from the area, no material should be removed. Seedling recruitment in wet areas can be avoided by stacking dead material in dry areas, sites that should be the focus for follow up control. Herbicide (triclopyrtriethylammonium salt–Lumberjack™) applied to cut stumps as per Working for Water standard protocol, has been very effective, with no evidence of resprouting after treatment. No treatment of seedlings has yet been undertaken, but potentially a foliar spray could be used on juvenile plants after three years (reproductive onset is at five years) when densities of seedlings have declined and plants are bigger and therefore more visible. Identification of non-reproducing plants could be difficult as *M. parvistaminea* is easily confused with ericoid fynbos species (e.g. *Passerina* species). The aromatic, eucalypt-like smell of the leaves is however unmistakeable and a valuable quick and easy field identification tool.

We further suggest that as part of management operations the position of every plant, height (as the best predictor of age) and presence/absence of reproductive structures be measured to inform the adaptive management framework. The area searched should be recorded (using track logs), so that the completeness of survey can be confirmed. Standard control operations are likely insufficient to eradicate the species, so some additional intensive follow-up monitoring, to see if plants have been missed and determine effectiveness of control should be done (Zenni et al., 2009).

4.4. Eradication feasibility

Several factors suggest that the eradication of *M. parvistaminea* is a realistic goal (Simberloff, 2003, 2009; Panetta and Timmons, 2004; Panetta et al., 2011).

Serotinous species generally do not have seed dormancy adaptations and are relatively short-lived in the soil seed bank (Robinson, 2007). Our observations support this notion for *M. parvistaminea*, given that Robinson (2007) reported a seed viability of one year for the species. We therefore do not expect any germination from the seed bank after the fire at the Waterval site in January 2012. The absence of a soil-stored seed bank is arguably what minimizes the risk this species poses the most. When compared to species that store seeds in soil, not only does this reduce control costs, but also means that fewer clearing follow ups are required to declare areas as completely cleared. Fire could be a useful tool to kill adult plants and initiate a once off seed release event. In the absence of fire or clearing, *M. parvistaminea* can however release seeds intermittently through the death of stems (Robinson, 2007).

Lack of sufficient resources (including post-eradication surveys and follow-up) has been put forward as a reason for failed eradication projects (Simberloff, 2009). Ensuring that enough money is available from start to the end is thus vital to the success of an eradication project. As a core part of the mandate of the Invasive Species Programme at the South African National Biodiversity Institute (SANBI's ISP), there is a national organisation responsible for ensuring that the necessary resources are available until eradication is declared (Wilson et al., 2013). This study forms the basis for the eradication plan for this species, which SANBI's ISP will implement.

Although a formal cost–benefit analysis was not conducted in this study, we strongly believe that the substantial reduction of *M. parvistaminea* populations by 2014 (after initial clearing) will ensure that impacts are minimised. Benefits of eradication are assumed to be a reduction in the national invasion debt (Wilson et al., 2013) and conservation of native biodiversity with its associated benefits. Costs of follow up surveys and clearing will also be considerably less, suggesting a favourable cost–benefit ratio. Since forestry and nursery trials no longer take place at Kluitjieskraal forestry station (Poynton, 2009), we do not anticipate further reintroductions of the species via this pathway.

The eradication cost of ZAR 3,345,000 is uncertain, but with continued survey data and contextual info, estimates will be revised. Additional localities might be found, while if extra follow ups are deemed necessary (also if management effectiveness is low), the eradication cost is likely to increase. These uncertainties are why van Wyk et al. (2012) suggest that operating in an adaptive management framework where estimates of risk, cost and time are continually revised as contexts shift and information can be used to update the risk profile. This is only possible if data on the progress of management are collected and interrogated (e.g. on an annual basis).

In conclusion we recommend that an eradication plan is implemented against *M. parvistaminea* and that the species is listed under category 1a of the invasive species regulations of NEM:BA (Department of Environmental Affairs, 2014), i.e. requiring compulsory control. Given the invasive potential of this species and uncertainty around taxonomy of introduced species in the group we further suggest the need for a comprehensive assessment of invasive dry-fruited Myrtaceae in South Africa.

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Supplementary Material

Supplementary Material to this article can be found online at http://dx.doi.org/10.1016/j.sajb.2014.05.002.

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Melaleuca parvistaminea Byrnes (Myrtaceae) in South Africa: invasion risk and feasibility of eradication

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Supplementary material

S1: Discussion on initial misidentification of *M. parvistaminea*

The populations in the Tulbagh Valley are likely all *M. parvistaminea* and not *M. ericifolia* as originally thought. Revision of the identification is based on number of stamens, stamen length, leaf length and its reseeding regenerative strategy (S1.1), and has been confirmed by an expert in Australia (B. Lepschi, pers. comm. August 2013). Specimens and photographs identified as *Melaleuca ericifolia* (none as *M. parvistaminea*) were found in Compton Herbarium (NBG) (S1.2). However, none of these specimens (collected in 2011), except those from the Tulbagh-Wolseley area, were *M. parvistaminea*. These are likely *M. armillaris*, a common ornamental species that is clearly distinct from *M. parvistaminea. Melaleuca parvistaminea* was considered a variety of *M. ericifolia* until 1987 and has a similar distribution (Robinson 2007). Specimens in South African herbaria that were collected prior to 1987 were therefore all identified as *M. ericifolia*, and nomenclature for alien taxa was not regularly updated. Thus, in this instance, taxonomic uncertainty is likely derived from lack of expertise on this group and a lack of awareness of the splitting of *M. ericifolia* in 1987 (Albrecht 1987).

The proposed change in identification to *M. parvistaminea* was initially based on the plants in the field being reseeders and not clonal, which excludes *M. ericifolia* as a possibility (Robinson et al. 2006, Robinson 2007). An examination of the morphology confirmed this. The characters distinguishing *M. parvistaminea* from *M. ericifolia* are: 4-7 stamens per bundle, stamens to 4 cm long, flowers with pink petals (observed on buds, Fig. 2C), leaves 4-11 mm long and raised oil glands on the abaxial leaf surface (S1.1). The initial misidentification led to the expectation of low seed viability and primarily clonal spread in the populations (Robinson 2007). Profuse recruitment and 98.3% mortality of plants after fire at the Waterval site, and seedling cohorts near cut plants at the Kluitjieskraal plantation indicates however that this species primarily regenerates through reseeding; Robinson (2007) reports seed viability of up to 80%. Plants are not likely to invest in both reseeding and clonal strategies (Robinson 2007), thus further supporting the identification as *M. parvistaminea*.

The case of *M. parvistaminea* in South Africa is a good example of the need for correct identifications, and the crucial role of taxonomy in invasion ecology (Pyšek et al. 2013). The initial misidentification as *M. ericifolia* has led to a number of errors. At first we based decisions on incorrect biology (S1.1) (especially lower fecundity) and expected plants to prefer more inundated habitats. This shows how misidentifications can lead to incorrect management practices; Richardson and Rejmánek (2011) listed *M. ericifolia* as an invasive shrub, but have since changed the taxa to *M. parvistaminea* in a recent update of the list (Rejmánek and Richardson 2013). Invasive species lists are important tools for decision makers to allocate limited resources and to formulate policy and legislation and as such, errors are likely to be compounded when misidentifications are made (McGeoch et al. 2012) having negative consequences for national invasive species management.

More *Melaleuca* and *Callistemon* species are being recorded as naturalised and potentially invasive in South Africa (Wilson et al. 2013); three more *Melaleuca* species at the Kluitjieskraal wetland alone. Correct identification of a species is important for understanding its biology and ecology, which is a prerequisite for evaluating invasiveness. Ideally, taxonomic verification should be supported by molecular data. The lack of appropriate molecular data for this species and in Myrtaceae in general is being addressed according to a review by Grattapaglia et al. (2012), to further understand the phylogeny, phylogeography and taxonomy in the family. Invasions where trees have small, dry seeds that require a period of inundation (e.g. eucalypts) have not been prominent at a global scale. This group includes the genera *Callistemon*, *Eucalyptus*, *Kunzea*, *Leptospermum*, *Melaleuca*, *Metrosideros*, *Psidium* and *Syzygium*. There is a need for a broader assessment of potential invasiveness of this group. The popularity of the group in horticulture in South Africa, and therefore the wide-scale planting and high propagule pressure (important drivers of invasion success), calls for the development of local taxonomic expertise on these taxa in South Africa.

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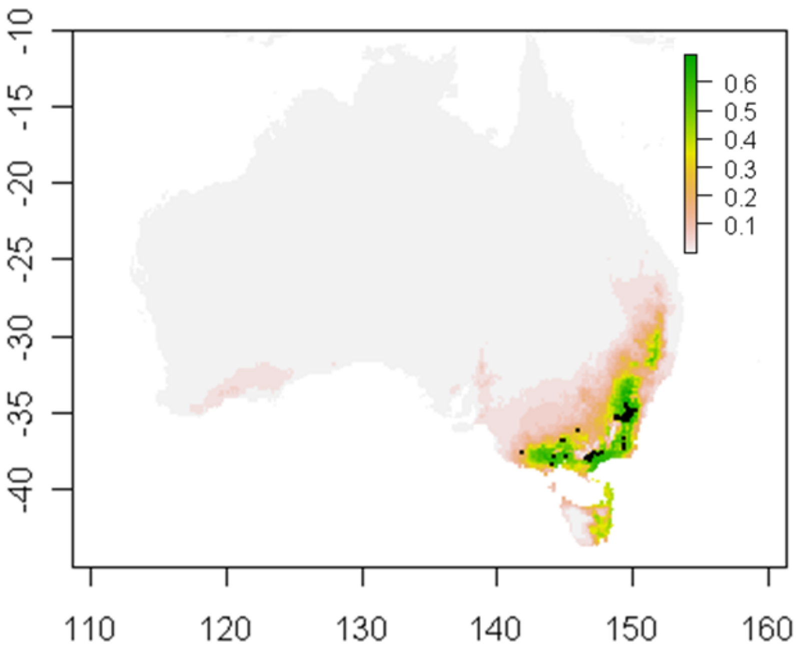
S1.1: Description of *Melaleuca ericifolia* (Wilson 1991a) and *M. parvistaminea* (Wilson 1991b) highlighting the key observed differences used to distinguish the two species (bold). Correctly identified *Melaleuca ericifolia* specimens were not available and were therefore not examined; corresponding features are underlined.

	Melaleuca ericifolia Sm. Swamp paperbark	*Melaleuca parvistaminea* Byrnes Rough-barked honey myrtle
Morphological features (http://plantnet.rbgsyd.nsw.gov.au/)	Shrub or small tree to 8 m high with <u>corky bark</u>. Leaves scattered or in whorls of 3, linear, mostly 7–15 mm long, c. 1 mm wide, veins not conspicuous, apex acute, glabrous; petiole to 1 mm long. Inflorescences many-flowered dense <u>spikes 0.7–1.7 cm long</u>; rachis shortly tomentose. Flowers solitary within each bract, <u>white</u>. Petals circular, c. 1 mm long. <u>Stamens 5–7 mm long</u>, <u>7–13 per bundle</u>; claw to 2 mm long. Fruit cylindrical, 2.5–4 mm diam., orifice 1.5–3 mm diam.; sepals persistent but obscure.	Shrub or small tree to 4 m high with **rough bark**. Leaves scattered or irregularly in whorls of 3, linear, 4–11 mm long, c. 1 mm wide, veins not conspicuous, **oil glands raised**, apex acute to obtuse, glabrous; petiole to 1 mm long. Inflorescences many-flowered dense **spikes 1–2.5 cm long**; rachis shortly tomentose. Flowers solitary within each bract, **white to cream**, **petals often tinged with pink**. Petals broad-ovate to elliptic, to 1.5 mm long. **Stamens 3–4 mm long, 4–7 per bundle**; claw to 0.5 mm long. Fruit cylindrical, c. 3 mm diam., orifice to 2 mm diam.; sepals persistent but obscure.
Regenerative and reproductive features	<u>Rootstock regenerator</u> (asexual)	**Seed-only regenerator** (sexual)
Native distribution in Australia	New South Wales, Victoria and Tasmania	New South Wales and Victoria
Natural habitat preference (Robinson, 2007)	Fresh to brackish swamps with <u>inundation lasting up to a few months</u>	Fresh water swamps with **short-term, intermittent inundation**
Invasiveness elsewhere (http://www.hear.org/gcw/)	"Weed" in Victoria and New South Wales	"Environmental weed" in Victoria and New South Wales

S1.2**:** *S*pecimens identified as *M. ericifolia* in Compton Herbarium (NBG) that were examined at the start of this study in June 2012.

Identification	**Accession/record number**	**Locality**	**= *M. parvistaminea***	**= *M. ericifolia***	**GPS coordinate**
Melaleuca ericifolia Sm.	NBG0262488	Waterval Nature Reserve	Yes	No	33.34208° S 19.11329° E
Melaleuca ericifolia Sm.	NBG0269364	Next to R340, Willowmore 3323CC	No	No	33.89167° S 23.18699° E
Melaleuca ericifolia Sm.	NBG270001	Somerset West	No	No	34.05022° S 18.83033° E
Melaleuca ericifolia Sm.	NBG0270036	Joostenberg, along Waarburgh Road	No	No	33.83090° S 18.73690° E
Melaleuca ericifolia Sm.	NBG0271362	Cape Agulhas, SANParks	No	No	34.73106° S 19.90667° E

S2: *Melaleuca parvistaminea* natural distribution in Australia and associated bioclimatically suitable areas (green shading shows most suitable areas), indicating a significant match (AUC=0.998) for the MaxEnt model. This model is projected onto South Africa in Fig. 2a



S3: *Melaleuca parvistaminea* pamphlets distributed to land managers asking for sightings. Note the leaflets refer to the species as *M. ericifolia* as they were produced prior to the correct identification being determined.

Front of pamphlet

What does it look like?

Melaleuca ericifolia (Myrtaceae) is a shrub or a small tree, 2–9 m high, with bark tearing off in pieces. **Leaves small, linear, dark green** and scattered or in whorls of three. Inflorescences many-flowered, in dense spikes. Leaves have a camphor smell when crushed. **Flowers small (up to 20 mm long), creamy white in colour** and can be seen from September to November. The fruit is a small cylindrical capsule containing numerous minute seeds.

Why is it important?

Melaleuca ericifolia is a proposed Category 1a invader plant. Under South African legislation, this means that it is prohibited and all existing plants must be eradicated. This alien plant species (native to Australia) grows along watercourses and seasonally inundated wetlands and will form dense thickets in wetlands. This poses a threat to water resources and water dependent biodiversity and related ecosystem services. This species can also tolerate well-drained situations. *Melaleuca ericifolia* can outcompete/exclude indigenous species and thus often form monospecific stands. The Early Detection and Rapid Response Programme (EDRR) is taking a precautionary approach and is in the process of collecting reports of its presence in southern Africa so we can eradicate it from the region before it becomes widespread.

What to do if you see it?

Please report sightings of these plants to the Early Detection and Rapid Response Programme (EDRR) staff at SANBI. Please do not remove any parts of the plant if you find it, as the seeds readily drop out of the fruits. If possible, provide us with a locality description, a photo and a GPS coordinate.

A, *Melaleuca ericifolia* bush about 3 m tall; B, *M. ericifolia* stems showing the rough bark texture; C, *M. ericifolia* flowers, 7–12 mm long. On the cover: *M. ericifolia* seeds.

Contact

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SANBI Graphics
November 2011

Back of pamphlet

S4: Evaluation of invasive risk of *Melaleuca parvistaminea* using the Australian Weed Risk Assessment scheme (Pheloung et al., 1999)

Question	Answer	Reference	Score	Range of possible scores
Is the species highly domesticated?	No	van Wyk et al. (2012)	0	0 or -3
Species suited to South African climates	High	Bioclimatic model	2	0, 1 or 2
Quality of climate match data (0—low; 1—intermediate; 2—high)	Intermediate	Bioclimatic model	1	0, 1 or 2
Broad climate suitability (environmental versatility)	No, restricted to SE Australia. temperate, warm summer	Köppen-Geiger climate zones	0	0, 1 or 2
Native or naturalised in regions with extended dry periods	No	WORLDCLIM data	0	0 or 1
Does the species have a history of repeated introductions outside its natural range?	No	Richardson and Rejmánek (2011)	0	0 or 1
Naturalised beyond native range	No	http://www.hear.org/gcw/	0	0, 1, 2, 3 or 4
Garden/amenity/disturbance weed	No		0	0, 1, 2, 3 or 4
Weed of agriculture/horticulture/forestry	No	http://www.hear.org/gcw/	0	0, 1, 2, 3 or 4
Environmental weed	yes	http://www.hear.org/gcw/	4	0, 1, 2, 3 or 4
Congeneric weed	Yes	http://www.hear.org/gcw/	2	0, 1 or 2
Produces spines, thorns or burrs	No		0	0 or 1
Allelopathic	Unknown, but leaves are aromatic and allelopathy is well-known in the family (e.g. *Eucalyptus* spp.)		0	0 or 1
Parasitic	No		0	0 or 1
Unpalatable to grazing animals	?			-1 or 1
Toxic to animals	?			0 or 1
Host for recognised pests and pathogens	No		0	0 or 1
Causes allergies or is otherwise toxic to humans	No		0	0 or 1
Creates a fire hazard in natural ecosystems	Yes, the species can create monospecific stands of large shrubs (> 3 m) not characteristic in natural Breede Shale Renosterveld		1	0 or 1
Is a shade tolerant plant at some stage of its life cycle	Yes, seedlings and adults grow well in shade of pine trees		1	0 or 1
Grows on infertile soils	?			0 or 1
Climbing or smothering growth habit	No		0	0 or 1
Forms dense thickets	Yes		1	0 or 1
Aquatic	No		0	0 or 5
Grass	No		0	0 or 1
Nitrogen fixing woody plant	No		0	0 or 1
Geophyte	No		0	0 or 1
Evidence of substantial reproductive failure in native habitat	No		0	0 or 1
Produces viable seed	Yes		1	-1 or 1
Hybridises naturally	?			-1 or 1
Self-fertilisation	?			-1 or 1
Requires specialist pollinators	No, flowers have		0	0 or -1

	generalist characteristics			
Reproduction by vegetative propagation	No		-1	-1 or 1
Minimum generative time (years)	5 yrs		-1	-1, 0, or 1
Propagules likely to be dispersed unintentionally	Yes, by workers or vehicles		1	-1 or 1
Propagules dispersed intentionally by people	No		-1	-1 or 1
Propagules likely to disperse as a produce contaminant	No		-1	-1 or 1
Propagules adapted to wind dispersal	Yes, seeds are small and can therefore be dispersed by wind.		1	-1 or 1
Propagules buoyant	Yes, seeds are small and may be buoyant for short distances		1	-1 or 1
Propagules bird dispersed	No		-1	-1 or 1
Propagules dispersed by other animals (externally)	No, although spread by baboons can't completely be disregarded		-1	-1 or 1
Propagules dispersed by other animals (internally)	No		-1	-1 or 1
Prolific seed production	Yes		1	-1 or 1
Evidence that a persistent propagule bank is formed (> 1 yr)	No		-1	-1 or 1
Well controlled by herbicides	Yes		-1	-1 or 1
Tolerates or benefits from mutilation, cultivation or fire	Yes, seeds are released from serotinous capsules after fire and clearing thus promoting spread	This study	1	-1 or 1
Effective natural enemies present in Australia	No		-1	-1 or 1

References

Pheloung, P.C., Williams, P.A., Halloy, S.R., 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57, 239-251.

S5: Species report

Species: *Melaleuca parvistaminea* Byrnes (Myrtaceae), (van Wyk 1, NBG-262488). No subspecific information available

Location: South Africa

Status: Invasive; E under Blackburn; not known to be cultivated recently (possibly introduced for arboreta trials before 1990)

Potential: coastal areas of the southern parts of the Western Cape are suitable, but likely establishment depends more on site specific conditions, such a seasonal inundation and fire.

Abundance: ~26 000 plants (2012); 1.15 ha (condensed area); numerous seeds stored on plants in serotinous capsules.

Population Growth Rate: not known, but expansion will be episodic based on recruitment events triggered by fire and water availability

Extent: 2 populations over 1 800 ha

Spread: Unknown, thus far no evidence of long distance dispersal. Dispersal is via wind and water. Still restricted to sites at Kluitjieskraal and Waterval, near the towns of Wolseley and Tulbagh.

Impact: Monoculture created, potential transformer species that uses excessive resources and is a fire promoter (sensu Richardson et al. 2000) For an Australian Weed Risk Assessment 41 of 49 questions answered, score = 9, see Jacobs et al. in review.

Threat: Not quantified

Survey method(s) used: Systematic walked transects to generate point distributions. Pamphlets were circulated to land owners, herbarium specimens and the spotter website, www.ispot.org.za, were examined, explicit efforts at site delimitation found no plants outside the area.

Notes: eradication plan in place, with an initial estimate that eradication can be declared by 2021 at a cost of ZAR 3 475 000 (US$ 355 400).

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References

Jacobs, L. J., Richardson, D. M., Wilson, J. R. U. *Melaleuca parvistaminea Byrnes (Myrtaceae)* in South Africa: Invasion risk and feasibility of eradication, South African Journal of Botany (2014), http://dx.doi.org/10.1016/j.sajb.2014.05.002

Richardson, D.M., Pyšek, P., Rejmánek, M., Barbour, M.G., Panetta, F.D., and West, C.J., 2000. Naturalisation and invasion of alien plants: concepts and definitions. Diversity and Distributions 6, 93-107.

Pheloung, P.C., Williams, P.A., Halloy, S.R., 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57, 239-251.